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Design of a plasmonic absorber based on the nonlinear arrangement of nanodisk for surface cloak

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ABSTRACT

Characterization of a plasmonic absorber for surface cloaking is proposed in this work. The improvement in the absorbance is obtained by using nanodisk particles array, and it is shown that the nonlinear structure increases the bandwidth of the absorber and reduces the reflectance by phase controlling on the surface. In this study, a corner surface with a refractive index of 3.46 is assumed as the main object which is located over a gold layer in the role of the ground for omitting the transmission and then we have implemented the nanodisks in three rows for each side of the corner with a radius of 45 nm. It is demonstrated that by utilizing this arrangement, we can obtain a reflection of −14 dB at 150 THz with a bandwidth of 8 THz for the reflecting less than −10 dB. In the following, it is illustrated that applying the nonlinear radius arrangement will increase the bandwidth to 18 THz and as a result, a bandwidth enhancement of 100% will be gained. Furthermore, the parametric studies have been used for realizing the elemental effect on improving the bandwidth. The proposed plasmonic absorber consisting of a nonlinear arrangement of nanodisks opens new prospects for surface cloaking.

1. Introduction

When the electromagnetic wave is incident on the surface of an object, the reflected wave will scatter and illuminate the object for the viewer. Reducing this scattered wave from an object is the main purpose in radar stealth and other applications including remote sensing, Radome and medical or biological measurements [1]. In the past decade, by the appearance of metamaterial technology, different applications of metamaterial have been found in the optical regime such as cloaking for the electromagnetic invisibility of an object [2]. The metamaterial cloak characteristics have been developed by an isotropic homogeneous coat for spherical and cylindrical invisibility cloaks to reduce the far-field radar cross section (RCS) [1,3]. The metamaterials have been studied for various THz and optical applications [4].

The full-wave solution pertaining to plane-wave-excited configurations has been developed for spherical cloak/anti-cloak interactions based on Mie theory by the combination of transverse electric (TE) and magnetic (TM) components [5]. In addition, various types of bi-layer or multilayer spherical and cylindrical cloaks have been developed [6,7]. Recently the full-wave analysis method such as Finite Difference Time Domain (FDTD) has been evolved based on basic mathematical model and studied the scattering cross section (SCS) [8,9]. In other words, FDTD has been developed with the focus on complicated structures same as elliptical [10] or cloaked objects with illusion media [11].

An equivalent circuit model proposed by Zhang et al. in order to describe the multilayer spherical cloak and shows that how the dual-frequency cloak modeling with the LC-unit is possible [12]. On the other hand, in nature, we encounter with arbitrary structures in various applications, which in that full-wave study around these topics is noticed for cloaking these structures [13–15].

In order to improve the RCS and cloak in different shapes, a number of techniques have been investigated including matching the speed of sound to acoustic impedance for better cloak performance than Cummer–Schurig cloak [16], anti-plane elastic waves using two alternative techniques of homogenization and hyper-elasticity [17] and broadband acoustic cloaks based on the homogenization of layered materials [18]. In addition, scattering characteristics of the cloak have been noticed to minimize the scattering based on the full-wave analysis modeling [19,20] and for reducing the SCS, a method same as

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the complementary medium is developed [21]. Furthermore, various experimental cloak models are proposed for visible light [22].

In the optical region, the plasmonic absorber has been built up for solar cells [23] and cloak applications [24]. The interaction between the light photons and the electrons of the metal makes the electrons be aroused, contained energy and charged at the same time which in this reformation they are called polaritons. When the polaritons are placed on the interface between the dielectric and metal, they are called surface plasmon polaritons (SPPs) and the collective movements of these SPPs are known as plasmonic characteristic. The plasmonic characteristic is noticed in optical regimes for various applications with manipulating and controlling the incident wave [25]. Recently, several types of the plasmonic absorbers have been studied such as nanodisk [26] and nano cylindrical structures [27]. Moreover, some attempts have been done for the dual polarized or nonlinear arrangement of the cloaks [28,29] and also the nonlinear arrangement of the nano disks array for wider bandwidth [30]. However, the structure of this array has been used for the smooth surfaces and the low absorption is the main drawback of this kind of absorber.

In addition, rectangular plasmonic absorbers have been fabricated for dual band or wider bandwidth in optical regime [31,32].

In this work, we have suggested a novel arrangement of the nanodisks for improving the absorber bandwidth.

Based on previous research on carpet surface and phase effect on Snell low reflection, we have presented a new study on nanodisks arrangement for the surface cloak. In other words, a new plasmonic coat based nanodisk has been discussed for designing an absorber and obtaining an invisible surface. In this study, a corner surface with high reflection determined which with the combination of the nanodisks, the reflection reduced drastically at 155 THz. In order to enhance the bandwidth, we have suggested a nonlinear arrangement of nanodisks which led to amending the bandwidth up to 100%. The phase response is revealed that how the nonlinear arrangements help to bandwidth enhancement. To be more clarified, we show that by utilizing nonlinear arrangement, we are able to control the phase in the absorber prototype and therefore the distortion between incident and reflection angles will be reduced.

2. Design procedure

Based on the invariance of Maxwell equations throughout the transformation, the permittivity and permeability tensors of the medium in the physical space can be expressed as:

$$\varepsilon = \mu = \frac{\Lambda \Lambda^T}{\det(\Lambda)} \tag{1}$$

where $\Lambda = \frac{\partial(x',y',z')}{\partial(x,y,z)}$ is the Jacobian matrix which relates the virtual space (x, y, z) to the physical space (x', y', z').

For a cloak with homogeneous trait, the following linear transformation is presumed:

$$x' = \alpha_1 x + \beta_1 y + \gamma_1 z, y' = y, \quad z' = \alpha_2 x + \beta_2 y + \gamma_2 z \tag{2}$$

The result of (1) and (2) as the parameters of cloak are :

$$\varepsilon = \mu = \frac{1}{\det(\Lambda)} \begin{bmatrix} \alpha_1^2 + \beta_1^2 & \alpha_1\beta_2 + \alpha_2\beta_1 & 0 \\ 0 & 0 & 1 \\ \alpha_1\beta_2 + \alpha_2\beta_1 & \alpha_2^2 + \beta_2^2 & 0 \end{bmatrix} = \frac{1}{\det(\Lambda)} \begin{bmatrix} \alpha & \beta & 0 \\ 0 & 0 & 1 \\ \beta & \gamma & 0 \end{bmatrix} \tag{3}$$

On the other hand, the phase of the nanodisks can be considered as a main parameter for controlling the angle of the incident wave.

In the carpet surface, the phase controlling is significant for cloaking [33] and the Snell's law of reflection is described by (4) [33,34]:

$$\sin(\theta_r) - \sin(\theta_i) = \frac{1}{k_i} \frac{\partial \Phi(x)}{\partial x} \tag{4}$$

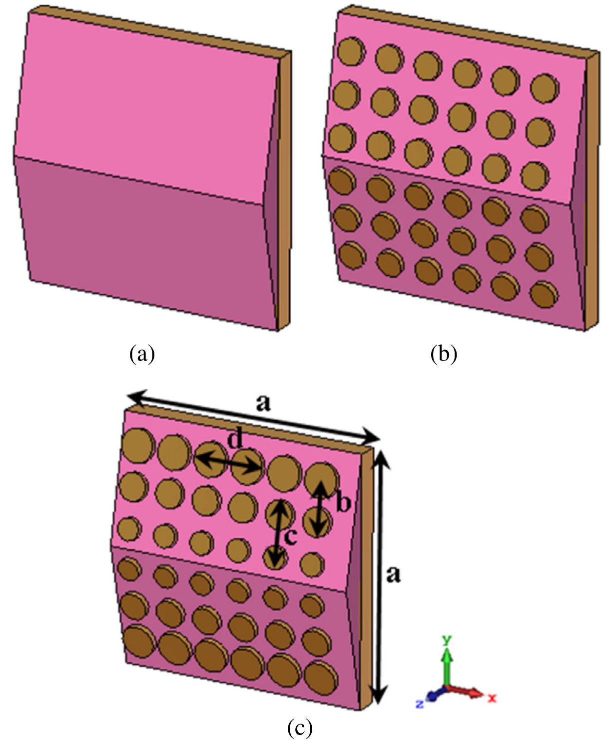

Fig. 1. (a) proposed surface for invisibility (b) the coated surface with plasmonic disk in linear arrangement (c) the coated surface with plasmonic disk in nonlinear arrangement.

where θ_i and θ_r are the incident and reflection angle respectively, ki is the wavevector in the incident medium and $\Phi(x)$ is the phase distribution. Based on Eq. (4), by controlling the phase variation, we are able to omit the distortion in the Snell's law and making a cloak surface.

Therefore, by controlling the phase distortion we can improve the reflection bandwidth of the cloak and the nonlinear arrangement is one of the greatest techniques for achieving linear phase distribution. Fig. 1(a) shows the 3D view of the proposed structure containing a corner silicon layer with refractive index of 3.46 which is placed over a gold layer and utilized for reducing the transmission (S_{21}) with the thickness of 80 nm. The maximum height of the dielectric layer is 100 nm and the metal layer dimensions are 900 × 900 nm^2. Finally, the nanodisks are placed in six rows over the bare surface as shown in Fig. 1(b). In this case, we have assumed similar disks with the radius and height of 45 and 20 nm respectively. Also the Palik model (Palik gold) as plasmonic model for gold is performed to represent the nanoparticle (nano disks) and ground layer. In the second case, the nonlinear arrangement is performed for boosting the absorbance and achieving wider bandwidth. To accomplish this, we have exerted the disks with a radius of 40, 50 and 60 nm and also the height of the nanodisk assumed as 20 nm (Fig. 1(c)). Furthermore, the other dimensions of the prototype are a = 900 nm, b = 249 nm, c = 233 nm and d = 260 nm.

3. Simulation and results

The CST Microwave studio has been utilized as commercial full-wave electromagnetic simulation software to achieve the absorbance and reflection properties of the prototype with and without the plasmonic layer. We have used the periodic boundary condition where PMC (perfect magnetic conductor) and PEC (perfect electric conductor) are used for X and Y directions respectively. Also, open and space boundary